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Review

Latent Benefits and Toxicity Risks Transmission Chain of High Dietary Copper along the Livestock−Environment−Plant−Human Health Axis and Microbial Homeostasis: A Review

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ABSTRACT: The extensive use of high-concentration copper (Cu) in feed additives, fertilizers, pesticides, and nanoparticles (NPs) inevitably causes significant pollution in the ecological environment. This type of chain pollution begins with animal husbandry: first, Cu accumulation in animals poisons them; second, high Cu enters the soil and water sources with the feces and urine to cause toxicity, which may further lead to crop and plant pollution; third, this process ultimately endangers human health through consumption of livestock products, aquatic foods, plants, and even drinking water. High Cu potentially alters the antibiotic resistance of soil and water sources and further aggravates human disease risks. Thus, it is necessary to formulate reasonable Cu emission regulations because the benefits of Cu for livestock and plants cannot be ignored. The present review evaluates the potential hazards and benefits of high Cu in livestock, the environment, the plant industry, and human health. We also discuss aspects related to bacterial and fungal resistance and homeostasis and perspectives on the application of Cu−NPs and microbial high-Cu removal technology to reduce the spread of toxicity risks to humans.

KEYWORDS: *copper, livestock, plants, toxicity, microbial homeostasis, antibiotic resistance*

1. INTRODUCTION

Copper (Cu) is an essential trace element that is critical to all living organisms such as domestic animals, plants, microorganisms, and humans. High Cu additives in livestock diets, Cu−pesticides, Cu− fertilizer, and Cu−nanoparticles (Cu−NPs) are widely used, thus causing large amounts of Cu to be discharged into the environment.[1−3]

For domestic animals, Cu is involved in metabolic reactions such as cellular respiration, tissue pigmentation, and hemoglobin formation and can especially accelerate the growth performance and development of piglets.[2,4] Copper is also able to regulate metabolic processes in plants such as photosynthesis, electron transport, respiration, oxidative stress response, and a variety of signaling factors.[1,5] The natural organic Cu fungicide named C-coordinated *O*-carboxymethyl chitosan Cu(II) complex (O−CSLn−Cu) is capable of killing *Phytophthora capsici* Leonian.[3] Copper supplementation can improve anaerobic codigestion of food waste and domestic wastewater.[6] Moreover, Cu−NPs can improve the mechanical and antimicrobial properties of food packaging.[7] In particular, Cu is an essential nutrient for humans with a dietary reference intake estimated at 0.9 mg/day.[8] It helps in promoting digestion by binding to dietary fiber and traveling to the large intestine where it is released during fermentation by colonic bacteria.[9] Clearly, these events underscore how a potential transmission chain of heavy metal pollution risk is created.

Excessive Cu supplementation in the livestock feed industry causes soil and sewage pollution from feces and urine infiltration. Eventually, Cu may accumulate in livestock products (meat, eggs, milk, and processed food), aquatic foods, plants (fruits, crops, and vegetables), and drinking water and endanger human health. For example, the presence of Cu in low-cost snack foods has a potential risk of toxicity to children's health,[10] Cu in PM_{10} particles is 0.22 ng/m^3 and $PM_{2.5}$ particles is 0.86 ng/m^3, and exposure to Cu in the air may cause cardiovascular-related metabolite disorders by activating sphingolipids.[11] High Cu can lead to excessive accumulation in products such as oysters and vegetables and induce cytotoxicity in the human intestine and liver.[12,13] Copper exposure leads to an imbalance of the antioxidase system and severe oxidative damage, higher cytotoxicity, cell cycle arrest, and apoptosis of human gastric epithelial cells.[14]

Long time exposure to high Cu altered the microbial homeostasis in the environment and the gastrointestinal tract of livestock and humans. High Cu improves the environmental adaptability of soil microorganisms and induces toxicity in agricultural soils.[15] A study also indicated that high-Cu diets can alter the gut microenvironment and impact the composition and abundance of bacteria in livestock;[16] for example, dietary high Cu decreases the intestinal microbial diversity but increases the ratio of Firmicutes to Bacteroidetes in pigs.[17] Dietary Cu also enhances ruminal microbial

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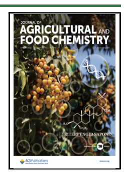

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